19 SEPTEMBER 1980 (FOUO 8/80) 1 OF 1

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JPRS L/9306

19 September 1980

USSR Report

EARTH SCIENCES

(FOUO 8/80)

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USSR REPORT

EARTH SCIENCES

(FOUO 8/80)

CONTENTS

PHYSICAL PROCESSES AT EARTHQUAKE FOCI

Moscow FIZICHESKIYE PROTSESSY V OCHAGAKH ZEMLETRYASENIY (Physical Proccesses at Earthquake Foci) in Russian 1980 signed to press 13 Feb 80 pp 2-6, 274-275

[Annotation, preface and table of contents from collection of articles edited by Academician M. A. Sadovskiy, Izdatel'stvo "Nauka," 1150 copies, 283 pages]

[Text] Annotation. This collection of articles includes materials from the All-Union Scientific Session "Physical Processes at Earthquake Foci," held during the period 16-19 May 1977 at Moscow. The published articles reflect the successes attained in the USSR during recent years in the field of many-sided investigation of physical processes at earthquake foci and which have won recognition in world geophysics. The papers devoted to the dynamics of focal zones demonstrate a considerable progress in investigation of processes transpiring at the present time at the foci of strong earthquakes of past years. The materials in the collection of articles give the physical and methodological basis for solution of the important national economic problem "Prediction of Time, Place and Intensity of Earthquakes" and define ways in which to solve problems relating to the prediction of the effect of earthquakes on structures on the basis of physical and computed models of earthquake foci.

The book is intended for geophysicists, seismologists and geologists.

Preface. The foundation for a new stage in the study of earthquakes has now been laid. The investigation of focal processes, while remaining a component part of seismology and geology, has ceased to be their monopoly -- it has become a significant branch and problem in geophysics as a whole, also advancing the creation of geodynamics of the earth's deep layers. In actuality, it is now already quite obvious that without study of deformations of the earth's crust, investigations of electromagnetic phenomena -- natural and artificial, geothermal and hydrological regimes, without an understanding of the physico-geochemical processes of changes in the state of matter there can be no adequately complete attempt at explaining and describing focal processes, their genesis, manifestation, and also their influence on the dynamics of the earth's deep layers.

The materials presented in this collection of articles, together with other materials on the physics of destruction, laboratory experimentation and observed changes in geophysical fields in the focal zones of earthquakes, will make it possible, in our opinion, to draw three extremely general conclusions of a physical and methodological character applicable to the problems of prediction and control of earthquakes.

The first is that the main faults, forming dynamically or quasistatically (slowly), have externally identical stage patterns of preliminary fissuring. This means that a strong earthquake and the forming or opening-up of a fault of the same length with slippage without significant radiation of elastic waves must be preceded by similar disturbances of geophysical fields -- precursors, that is, there can be baylike "normal" precursors without earthquakes. Here arises the fundamental problem, evidently not without prospects, of finding the fine difference between similar disturbances in the stage of brief precursors.

The presence of "temporal" bays in geophysical fields was noted in investigations on Kamchatka; anomalies in the Ashkhabad polygon possibly also have this physical nature.

The second conclusion relates already to the possibility of earthquake control. It has been demonstrated in laboratory experiments that transition from stable slippage along an existing fault to dynamic rupturing is dependent on hydrostatic pressure and the physical state of the matter between the blocks. Here, evidently, fundamental possibilities exist for the preventing of earthquakes, at least in fault zones emerging at the surface, by technical means (shots, pumping in of water or its pumping out, etc.) for changing the stressed state of the medium or the physical state of the matter between blocks.

This conclusion in itself is not exceptionally new. Some experiments with samples and in the field have already been made in the United States and are being prepared in the USSR. It is also obvious that fundamental questions arise as to whether a still stronger earthquake is not provoked elsewhere, the extent of the faulting, etc. However, it is important that the means available for physical research are becoming increasingly clear.

The last conclusion, on a practical basis, is possibly the most important, although in general it is already known that there is a need for specialization of observation and interpretation systems in dependence on the scales (magnitudes) of an earthquake which must be predicted. This specialization must include, first of all, the very observation methods: the greater the impending earthquake, the larger will be the preliminary faulting which precedes it and accordingly the observation methods in principle must allow averaging of field changes at the corresponding spatial scales. Second, the interpretation methods must ensure the smoothing of individual local disturbances both in space and in time at suitable scales.

On the other hand, the classical basis of seismology -- the theory of elasticity -- cannot ensure the present-day development of this science.

The theory of destruction of materials, especially the mechanics of destruction, is now more and more becoming the new physical foundation of the present stage in seismology. This process is complex, sometimes ambiguous, since the physics and mechanics of destruction are in the process of their development, experiencing vigorous development from the beginning of the 1960's.

Finally, a factor of more than a little importance is that in contrast to the theories of elasticity, viscosity and plasticity the use of the advances in the physics of destruction of technical materials and rock samples at the spatial-temporal scales of destruction of rock masses is fundamentally more complex and much less obvious.

After examining this fundamental methodological problem, we arrive at an important conclusion: only direct geological-geophysical field observations of the destruction of the earth's masses can and should set the limits and define the area of application of the theories of destruction developed for small scales and will make it possible to clarify the general laws of destruction, ranging from inter- and intragranular fissures through dislocations within and between gigantic blocks of the nonuniform terrestrial crust and mantle matter.

It can also be said that the physics of microdestruction also is in need of the results of investigations of peculiarities of destruction of the earth's masses: the last stage in predestruction, transpiring before the formation of a "through" main fracture (third stage of creep in mechanics), occurs at the foci of earthquakes millions of times more slowly, and accordingly, in principle is more accessible to detailed investigation than microsecond processes in samples. Accordingly, geophysics very rightfully must be added to those sciences on whose attainments is dependent, according to the assertion of the leading specialists in the field of the modern mechanics of destruction, the further development of the physics of destruction.

This collection of articles contains materials from the first all-union session devoted to processes at earthquake foci, whose main themes were problems related to the physics of earthquake foci, and even more broadly, the physical principles of modern seismology. Seismology has been and remains the most informative field of geophysics in the study of deep structure. However, determination of discontinuities in the earth, elastic properties and some other peculiarities of deep structure nevertheless are not sufficiently complete characteristics of the earth's properties.

However, study of earthquake foci evidently will afford a possibility for penetrating both into the more "intimate" rheological properties of terrestrial matter and into the dynamics of the processes of its upper "shell."

A glance at prognostic studies which are being made, and in part those which are being planned, from this point of view indicates their inadequacy in the search for precursors and prediction of catastrophic earthquakes, the processes of whose preparation must involve areas of hundreds and millions of square kilometers.

In this connection it is very important to develop methods for long-range prediction in order to avoid excessive concern about local disturbances observed at individual points.

In conclusion it must be emphasized that modern physics has already blazed the trail to study of focal processes. This direction has been recognized also on a world scale: in England in 1977 a special symposium was devoted to the physics of earthquake foci at a session of the international association for study of physics of the earth's deep layers and in November of that same year, in East Germany, there was a special conference of the commission on applied geophysics on physical processes at foci.

It is entirely obvious that solution of the problems of earthquake prediction and progress in the physics of earthquake foci in the Soviet Union will require improvement of the experimental base and computation equipment.

We feel that the session organized by the Interdepartmental Council on Seismology and Seismic-Resistant Construction, in addition to discussions of the scientific results and their prospects, was also an arena for the discussion and recommendation of means for solving problems in technical re-equipping.

We express appreciation to Corresponding Member USSR Academy of Sciences S. L. Solov'yev, Academician Kazakh Academy of Sciences Zh. S. Yerzhanov, Doctor of Physical and Mathematical Sciences G. A. Sobolev, Candidate of Physical and Mathematical Sciences O. G. Shamina and Candidate of Physical and Mathematical Sciences S. D. Vinogradov, who did much work on the editing of this collection of articles and its preparation for the press, and also L. Ye. Borisova and L. I. Makeyeva for technical preparation of the manuscript.

M. A. Sadovskiy and V. I. Myachkin

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DETAILED INVESTIGATION OF SEISMOTECTONIC DEFORMATION OF PETER I RANGE

Moscow IZVESTIYA AN SSSR, FIZIKA ZEMLI in Russian No 4, 1980 pp 39-50

[Article by A. A. Lukk and S. L. Yunga]

[Text] Features of the mechanisms of weak earthquake epicenters ($M \leq 4$) in central Garmskiy Rayon, represented by the Peter I range, are examined in the article. Associated with each mechanism is coefficient of correspondence k^{α} to the general course of seismotectonic deformation in the Peter I range. The spatial distribution of correspondence coefficients k^{α} is analyzed. Sections with low mean correspondence coefficients and at the same time a high level of seismicity are interpreted as zones of increased macrofracturing of the earth's crust. Earthquakes with a nonquadratic distribution of the signs of the first manifestations of P-waves occur in those zones. This effect is interpreted as the manifestation in the epicenters of such earthquakes of complex displacements without separation.

1. Introduction

The region of transition from Pamir to Tien Shan in the area of Garm is the subject of many years of geophysical research. The first representations of the mechanism of epicenters of that region were based on data from seven seismic stations (135 earthquakes) from 1950-1956 [1]. Regular determinations of the mechanisms of weak earthquake epicenters ($M \geq 1.5$) on the basis of data from 10-15 seismic stations have been conducted there since 1964 [2].

Ten more telemetry stations, located immediately in the zone of the maximum concentration of earthquakes within the confines of the Peter I range have participated in determinations of the mechanisms of epicenters since August 1975, in addition to 15 permanent seismic stations of the Complex Seismological Expedition (KSE) [3, 4]. A complete map of the network of presently operating semismic stations of KSE is presented in Figure 1.

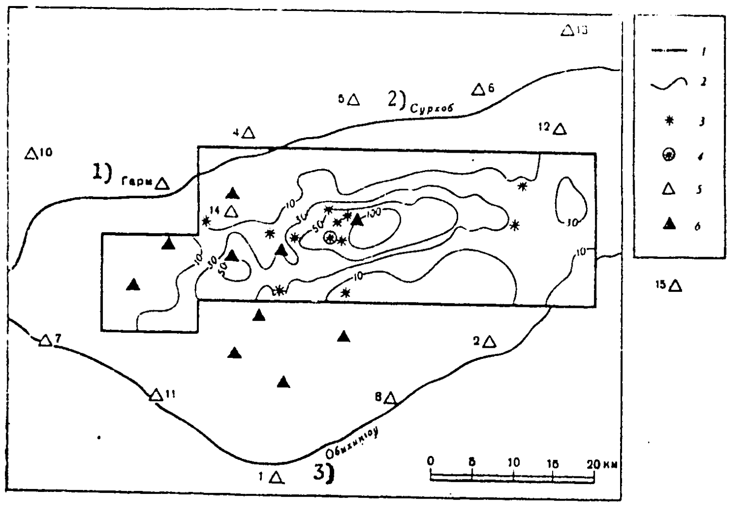

Figure 1. Map of density of determinations of earthquake epicenter mechanisms: 1 -- contours of examined uniformly deformed region of Peter I range; 2 -- isolines of number of determinations of epicenter mechanisms during entire observation period within sites measuring 2' × 2' (about 10 km^2); 3 -- epicenters of earthquakes with nonquadratic distribution of signs of first manifestations of P-waves; 4 -- group of five such epicenters; 5 -- stationary seismic stations; 6 -- seismic telemetry stations, established in 1975.

Key: 1. Garm 2. Surkhob 3. Obikhinyuu

An examination of experimental material disclosed a great diversity of orientations of the mean axes of compression and extension in the earthquake epicenters and the existence in exactly the same location of displacements, faults and upthrusts with the axes tending to acquire certain orientation and with a tendency for a certain type of movement to predominate [2].

The application of theoretically sound averaging methods during the analysis of epicenter mechanisms made it possible on the basis of about 2,200 earthquake mechanisms with $M \leq 4$ to establish basic tendencies of seismotectonic deformation (STD) in the region [5]. Representations developed in the literature [5] are suitable for describing the integral characteristics of seismotectonic deformation, but the diversity of individual events of the seismotectonic process, individual features of the epicenter mechanism of individual earthquakes, inevitably are obscured. The basis for a detailed analysis of individual features of the epicenter mechanism on a long-term STD background was established as a result of determination of the principles of STD.

Two classes of such features are examined in this work. The first class includes rather common cases of epicenter mechanisms, for which the orientation of the equivalent dipole source rarely does not match up with the main directions of long-term seismotectonic deformation. These features of epicenter mechanisms have a tendency to be grouped in space and time. Attempts have been made to associate their appearance with the preparation of strong earthquakes [6]. The other class of features of the epicenter mechanism combines events, during which the distribution of the signs of the first manifestations of P-waves on the surface of the sphere surrounding an epicenter differs from the quadratic distribution that corresponds to the slippage of the rocks of the earth's crust along one plane of a fault during ordinary earthquakes. Nonquadratic distributions of the signs of manifestations were observed previously for certain earthquakes in Japan [7-10], the Kurilo-Kamchatka zone [11] and Garmskiy Rayon [12, 13]. The equivalent dipole source, discovered as a result of superposition (usually employed for interpreting epicenter mechanisms) of a source in the form of the deformation of pure displacement and of a source in the form of three-dimensional deformation, was utilized in [7-10] for the purpose of explaining the observed distribution of the signs of the first manifestations. In this case an additional fourth independent parameter, characterizing the relationship between three-dimensional deformation and shear deformation, is introduced for describing the source. Presented in [11], evidently, are the first examples of interpretation, in which the source of deformation of pure displacement in the mentioned superposition was replaced by a source of complex shear deformation, so that there appears yet another parameter, the fifth, characterizing the kind of complex shear deformation. It is clear, however, that the larger the number of independent parameters is determined during interpretation of observation data, the less stable the final result will be. Therefore we tried to get by with just minimum changes in the procedure for interpreting epicenter mechanisms [12, 13] and to stay within the framework of representations of displacement, perhaps complex, in an earthquake epicenter. Thus, in cases when a nonquadratic distribution of the signs of the first manifestations is observed only one parameter is added, which describes the form of complex shear deformation. We note that the described method can be used to quite satisfactorily interpret the experimental material presented in the literature [8-11] as proof of the existence of a three-dimensional component of deformation in an earthquake epicenter. Since the tremendous number of direct and indirect observations argue in favor of shear deformation in an earthquake epicenter, we feel it best to revise the interpretation of epicenter mechanisms primarily at the cost of making shear deformation more complex. The introduction of a three-dimensional component may be viewed as the next step of the interpretation of complex cases. In this work we develop hypotheses which apparently were first advanced in [12], and demonstrate new examples of nonquadratic distribution of the signs of first manifestations. An attempt is also made to examine in conjunction with each other both classes of features of the earthquake epicenter mechanism and indirect information on the macrofracturing of the earth's crust in the examined territory.

2. Description of Experimental Material and of Method of Disclosing Epicenter Mechanisms That Do Not Conform with Long-Term Seismotectonic Deformation

Several uniformly deformed parts of the earth's crust were discovered as a result of an analysis of STD in Garmskiy Rayon [5]. One such area is a Mesocenozoic stratum of rocks in the Peter I range in the center of the rayon (Figure 1). The most favorable conditions for a detailed analysis of STD exist in that block. The overwhelming majority of earthquakes in that region are completely covered by seismic stations during determination of epicenter mechanisms, and in recent years at least one of the stations has been located right next to an epicenter [4, 12]. The level of seismic activity of weak earthquakes is maximum for the entirety of Garmskiy Rayon within the confines of the Peter I range, and for this reason most of the determinations of epicenter mechanisms have been concentrated specifically in that area. A map of the density of earthquake epicenters with determined epicenter mechanisms is given in Figure 1. The numbers on the isolines indicate the number of determined mechanisms for 2' × 2' sites (about 10 km^2) during a period of observations from December 1963 through April 1978 (the observations were interrupted from April 1969 through December 1972). The total number of determinations during that period was 971.

According to calculations [5], nearly horizontal compression on 135° azimuth with a large positive Lode-Nadai coefficient $\mu_m = 0.7$, predominates in the Peter I range. This line of deformation of maximum compression remains stable in time and its variations basically do not fall outside of a cone with a 20° aperture and an average angle of inclination to the horizon of $c = 7°$. Here intensity κ of mean mechanism M_{ij} remains basically within the limits of 0.3-0.45. We recall that $\kappa = (2M_{ij}M_{ij})^{1/2}$, where M_{ij} is the direction tensor corresponding to the mean mechanism.

A future objective of detailed analysis of STD of this uniformly deformed region will be an analysis of variations in time of the parameters of the velocity tensor of STD and disclosure of the elements of sharp misalignment of STD. The second aspect of this problem is illuminated in this work. Tensor M_{ij} is calculated on the basis of equally exact sliding samples of 100 individual epicenter mechanisms m_{ij}^{α} with displacement in 20 events. Individual earthquake mechanisms m_{ij}^{α} were examined on the background of time series of tensors M_{ij}. Coefficient k^{α}, characterizing the discrepancy between the main directions of tensors m_{ij}^{α} and M_{ij}, was calculated for each mechanism of earthquake No. α: $k^{\alpha} = 2\kappa^{-1}M_{ij}m_{ij}^{\alpha}$. We note that k^{α} does not exceed 1 in terms of modulus. Negative and near zero values of k^{α} indicate a discrepancy between earthquake mechanism m_{ij}^{α} and mean mechanism M_{ij}.

Thus, under the conditions described above of nearly horizontal compression the mechanisms of earthquakes of the thrust type do not conform with the deformed state of the Peter I range. Another objective of this work was to discover and establish the laws of three-dimensional distribution of these conflicting earthquake mechanisms.

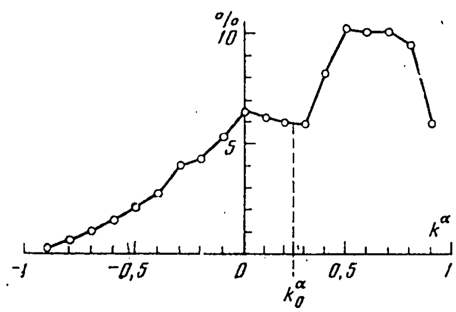

Figure 2. Distribution of number of mechanisms in percentage points out of total number of determinations based on similitude coefficients.

The boundary between conformal and nonconformal mechanisms of earthquake epicenters must be established at the outset. The distribution of the number of mechanisms in percentage points out of the total number of determinations of mechanisms based on the values of $\bar{k}^\alpha$ is plotted in Figure 2. Each value of $\bar{k}^\alpha$ was calculated as the average of 5 values of k^α, determined as a result of sliding transposition of a sample of 100 events during the determination of a time series of tensors of mean mechanisms. Figure 2 shows a distribution with two pronounced peaks and with a local valley near $k_0 = 0.25$. This value of k_0 is taken as the threshold for separating the mechanisms. Mechanisms for which $k^\alpha < 0.25$ will be assumed below to be inconsistent.

3. Procedure of Interpretation of Earthquake Epicenter Mechanisms with Nonquadratic Distribution of Signs of First Manifestations

We assume that at the initial moment of time in an earthquake epicenter there occurred an arbitrary shear deformation, not accompanied by a change of volume. Then, assuming the medium to be elastic and using Kelvin's solution concerning a concentrated force in an unbounded elastic medium, it is easy to find an expression for analyzing the elastic waves from an earthquake epicenter [14]. We apply theoretical data on displacement in the first manifestations of P- and S-waves to the surface of a unit focal sphere, surrounding an earthquake epicenter; we now reduce the amplitudes of the first manifestations of P- and S-waves to dimensionless form, dividing them by the theoretical maximum amplitudes of the first displacements in P- and S-waves. Then the first displacements in P- and S-waves in direction n_i may be described by the expressions

$$u_i^P = m_{kl} n_k n_l n_i, \quad u_i^S = m_{kl} (\delta_{ki} - n_k) n_i n_l,$$

where δ_{ki} is Kronecker's symbol; m_{kl} is the tensor of the moment of the dipoles whose axes coincide with the principal axes of the shear deformation in the earthquake epicenter. Since the spherical portion of the tensor is $m_{ii} = 0$ and intensity is $(2m_{ij}m_{ij})^{1/2} = 1$, the eigen-values of the tensor in diminishing order (m_1, m_2, m_3) may be represented through one Lode-Nadai coefficient μ_m:

$$\left\{ \frac{1}{2}\left(1 - \frac{1}{3}\mu_m\right)\left(1 + \frac{1}{3}\mu_m^2\right)^{-1/2}, \frac{1}{3}\mu_m\left(1 + \frac{1}{3}\mu_m^2\right)^{-1/2}, -\frac{1}{2}\left(1 + \frac{1}{3}\mu_m\right)\left(1 + \frac{1}{3}\mu_m^2\right)^{-1/2} \right\}.$$

It is easy to express the components of tensor m_{kl} through component μ_m and the direction cosines of the principal axes of extension t_i, intermediate b_i and compression p_i: $m_{kl} = m_1 t_i t_j + m_2 b_i b_j + m_3 p_i p_j$. The nodal surface for P-waves is in the general case the surface of an elliptical cone, the axis of which is oriented in the direction of extension t_i with $\mu_m < 0$ and in the direction of compression p_i with $\mu_m > 0$. Two ordinary mutually perpendicular nodal planes are a degenerate case of elliptical cone in the case of pure shear ($\mu_m = 0$ and $m_{kl} = 2^{-1}(t_i t_j - p_i p_j)$. The bisectrices of the right angles between these planes are oriented in directions t_i and p_i, and their line of intersection is oriented in direction b_i, corresponding to eigen-value $m_2 = 0$. With the described general type of epicenter mechanism may be associated a theoretical point source in the form of three orthogonal pairs of forces without moments. It is important to note that this type of source differs considerably from the theoretical source ordinarily used for describing an earthquake mechanism, represented as two orthogonal pairs of forces without moments (extension and compression) in that the former can be realized by displacements on a set of planes of faulres, whereas the second can be realized only on one of two planes, coinciding with the nodal planes.

We will not examine here the form of nodal surfaces for the SH and SV components of transverse waves, lying, respectively, in the horizontal plane and in the vertical plane of a seismic ray, since such an examination is completely unnecessary in practice[1]. For this purpose, for graphic representation of the results of interpretation of data on the signs of the first manifestations of S-waves, it is sufficient to represent the sign of first manifestation $SIGN_{SQ}$ of one of the components of S-waves, the displacement in which is oriented in direction **q**, through the sign of first manifestation of a P-wave in direction $(\mathbf{n} + \mathbf{q})\sqrt{2}/2$ or in direction $(\mathbf{n} - \mathbf{q})\sqrt{2}/2$. The necessary condition that sign $SIGN_{SQ}(\mathbf{q})$ coincide with the sign of manifestation of an SQ-wave, calculated theoretically from mechanism m_{kl}, is expressed as

$$SIGN_P[(\mathbf{n}+\mathbf{q})\sqrt{2}/2]=SIGN_{SQ}(\mathbf{q})=+1, \text{ if } SIGN_P[(\mathbf{n}\times\mathbf{q})]=-1,$$
$$SIGN_P[(\mathbf{n}-\mathbf{q})\sqrt{2}/2]=-SIGN_{SQ}(\mathbf{q})=-1, \text{ if } SIGN_P[(\mathbf{n}\times\mathbf{q})]=+1.$$

If in direction $\mathbf{n} \times \mathbf{q}$, in accordance with mechanism m_{kl}, the sign of the first manifestation of P-waves is expected to be negative, then $SIGN_{SQ}(\mathbf{q})$ is represented as the sign of manifestation of a P-wave in direction $(\mathbf{n} + \mathbf{q})\sqrt{2}/2$. In the inverse case sign $-SIGN_{SQ}(\mathbf{q})$ is represented as the sign of manifestation of a P-wave in direction $(\mathbf{n} - \mathbf{q})\sqrt{2}/2$. We note that such a representation of the signs of the components of S-waves makes it possible immediately to establish whether or not sign $SIGN_{SQ}$ conflicts with an earthquake epicenter mechanism.

The procedure for interpreting experimental data on first manifestation signs consists, as is known, in the separation of unlike signs of the nodal surface, which in the case at hand is the surface of an elliptical cone. This partitioning can be accomplished graphically [12], or with a computer, as was done in this work. In the latter case we sought the solution that corresponds to the maximum function of compatibility of the experimental and theoretical data [15].

4. Description of Types of Earthquake Epicenter Mechanisms Recorded in Peter I Range

Let us now proceed to an examination of the results of interpretation of data on the signs of the first manifestations of P-, SH- and SV-waves from certain earthquakes in the Peter I range. We note that we used the signs of manifestations of S-waves only in cases when the direction of the first movement on the corresponding component of an S-wave did not evoke the

[1] S. L. Yunga, "Instruktsiya po ispol'zovaniyu napravleniy dvizheniya v SH- i SV-volnakh pri graficheskom opredelenii mekhanizma zemletryaseniya" [Instructions on the Utilization of the Expressions of Motion in SH- and SV-Waves for Graphic Determination of Earthquake Mechanism], Fondy KSE IFZ AN SSSR, 1978.

slightest doubt. These cases make up about 25% of the examined recordings of first manifestations of S-waves. The signs of first displacements of P-waves, reproduced on the basis of data on S-waves, are encircled in Figures 3 and 4.

In the overwhelming majority of cases the signs of first manifestations are separated reliably on a stereographic projection by ordinary nodal lines, corresponding to a source in the form of two mutually orthogonal momentless dipoles. Characteristic examples of these determinations of earthquake mechanisms, a list of which is presented in Table 1, are shown in Figure 3. Mechanisms No. 2, 4, 6 are typical for the examined area of the Peter I range. Mechanisms No. 1, 3, 5 are not consistent with the long-term STD of this region. As follows from Figure 3, the reliability of determination of both types of mechanisms is quite high. Mechanisms that are not consistent with long-term STD in the Peter I range account for about 25% of the total number of determined epicenter mechanisms. Short-term variations of STD are occasionally related to local space-time increases of the number of inconsistent mechanisms, which apparently is a reflection of the dynamics of the seismotectonic deformation process.

Let us now examine earthquakes which exhibit a nonquadratic distribution of the first manifestation signs. To determine the mechanism of their epicenters we will use the source described in the preceding section, corresponding to complex displacement in the earthquake epicenter. The results of determinations of the mechanism of these earthquakes under the assumptions made above about the form of the source are presented in Table 2 and are partially depicted in Figure 4. Nodal lines corresponding to a quadratic distribution of signs, drawn as broken lines, are shown for some of the examples for comparison. An examination of Figure 4 shows that in virtually all cases the nodal lines of general form separate regions with different signs more reliably than the quadratic solution.

Earthquakes No. 1, 8 have first manifestations that are explicitly nonquadratic in nature. These two cases could not be interpreted successfully on the basis of a triple-dipole source.

The distribution of first manifestations for earthquake No. 7 differs only slightly from quadratic. This earthquake is a special case only because several similar earthquakes were recorded in the same location in August 1975 [11].

It is worthwhile to examine earthquakes No. 5, 6 and 12, for which all seismic stations recorded either only minus signs in the first P-wave manifestations, or only plus signs. The usual solution is not satisfactory in these cases. The description of mechanisms of these earthquakes in the form of centers of compression and expansion is not consistent with the existence of pronounced first manifestations of S-waves at many stations for earthquakes No. 5 and 12. By using these

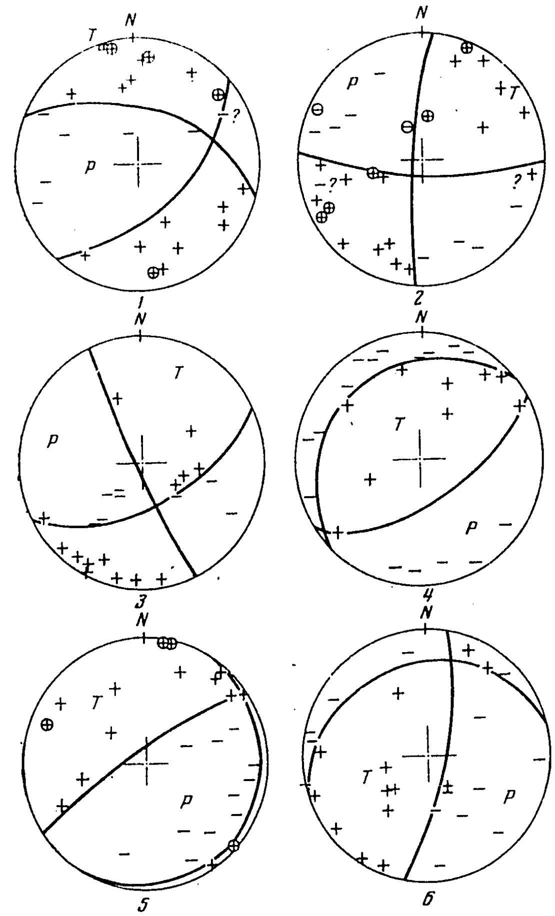

Figure 3. Characteristic examples of determination of earthquake epicenter mechanisms by standard procedure (equiarea projection of top hemisphere).

manifestations of S-waves it is possible to quite reliably determine the mechanism of earthquake epicenters in the form of complex displacements. An analogous solution is also possible for earthquake No. 6.

The orientation of the principal axes of the mechanisms corresponding to complex displacements is entirely consistent with the long-term STD of the Peter I range. At the same time there are among them several mechanisms

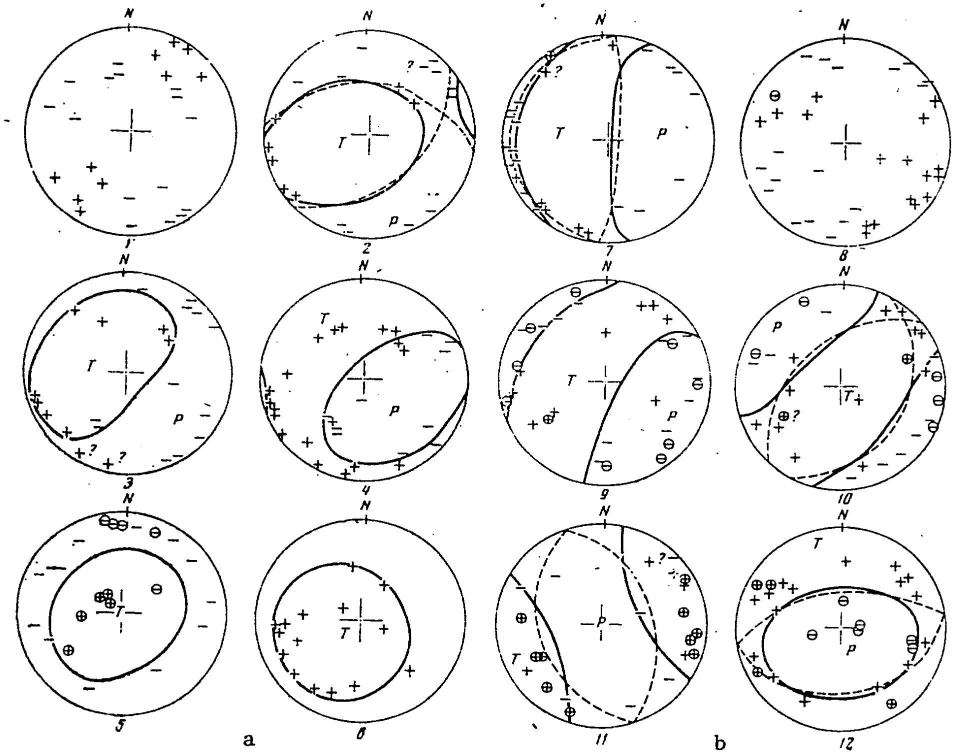

Figure 4. Mechanisms of earthquakes interpreted as manifestations of complex shear deformation in epicenters (same projection as in Figure 3).

that are not consistent with the long-term seismotectonic deformation (No. 8, 11, 12), just as in the case of mechanisms with simple movement in an earthquake epicenter.

5. Identification of Zones of Increased Macrofracturing of Crustal Rocks in Peter I Range

Let us examine the spatial correspondence between the number of consistent and inconsistent (in relation to STD) mechanisms of earthquake epicenters. For this purpose the entire examined territory was partitioned into 2' × 2' (about 10 km^2) overlapping cells, overlapping by one-half, and the ratio χ of the number of inconsistent mechanisms to the number of consistent mechanisms during the entire observation period was computed in each cell. The value of χ was not computed if the total number of determinations of mechanisms in a cell was smaller than 10. A map of isolines of χ is shown in Figure 5. An appreciable difference can be seen in the average values of χ between the western and eastern parts of the Peter I range. There is an overall increase of the average level of χ values in the western part of the Peter I range. This means that it is specifically there that earthquakes with inconsistent epicenter mechanisms are concentrated and the average STD principles inherent to the Peter I range as a whole are strongly violated.

It is interesting to combine the map of the values of ratio χ with the map of earthquake epicenter density. The map of representativeness of the determinations of mechanisms, presented in Figure 1 and copied by two isolines in Figure 5 may be used as an analog of the second map. Judging by general physical considerations the zones in which both schemes have high values can be expected to be identical to zones of increased macrofracturing of crustal rocks within the Peter I range. These areas are hatched in Figure 5. Two sharply outlined isometric zones are identified in the western and central parts of the examined territory with linear dimensions of 7 and 13 km, respectively. Returning to Figure 1, we see that all the earthquakes that we know of in the region with a nonquadratic distribution of signs of first manifestations of P-waves have occurred specifically within these two zones of increased macrofracturing of crustal rock. This feature of the directivity of radiation of seismic waves during earthquakes in zones of increased macrofracturing apparently can be associated with a high probability of complex displacement in the fractured medium.

6. Discussion of Results

Let us engage in a qualitative description of possible mechanical processes that produce earthquakes with the above-described features of epicenter deformation events. We must first make sense of a rather large number of earthquakes, the epicenter mechanisms of which are inconsistent with the long-term STD. We propose the following model of the occurrence of such earthquakes. At the present stage of tectonic deformation of a

Table 1.

№	1) Дата	2) Время, ч мин	3) Координаты гипоцентра			6) Магнитуда M	7) Ось сжатия P		8) Ось растяжения T	
			4) с. ш.	5) в. д.	H, км		Az	α	Az	α
1	22.IX 1975	04 41	38°56′	70°25′	6	2	252	32	346	86
2	20.X 1975	05 17	38°57′	70°31′	6	2	322	7	52	87
3	10.VI 1976	10 21	39°16′	70°41′	7	5	285	75	20	70
4	6.IX 1976	16 20	38°57′	70°36′	6	2	148	70	328	22
5	27.II 1977	01 04	38°55′	70°22′	8	3	158	35	328	53
6	25.XII 1977	16 18	38°58′	70°37′	5	5	120	60	255	35

Table 2.

№	1) Дата	2) Время, ч мин	3) Координаты гипоцентра			6) Магнитуда M	7) Ось сжатия P		8) Ось растяжения, T		μ_m
			4) с. ш.	5) в. д.	H, км		Az	α	Az	α	
1	24.V 1964	16 36	38°58′	70°48′	10	4	—	—	—	—	—
2	16.IV 1966	00 37	38°58′	70°35′	5	3	150	88	252	22	−0,13
3	16.IV 1966	15 50	38°57′	70°33′	5	4	49	80	296	30	−0,13
4	25.IV 1966	07 32	38°59′	70°33′	8	4	124	35	332	56	0,2
5	5.IX 1974	02 38	38°53′	70°35′	8	2	135	90	0	0	−0,5
6	22.III 1975	09 20	39°05′	70°49′	18	3	—	—	248	20	−1
7	14.VIII 1975	18 38	38°57′	70°33′	3	2	98	55	278	35	0,1
8	22.IX 1975	14 40	38°57′	70°30′	6	2	—	—	—	—	—
9	13.II 1976	06 53	38°53′	70°29′	7	2	113	66	265	26	0,2
10	30.VIII 1976	14 18	38°57′	70°28′	6	2	312	85	196	10	0,3
11	2.IX 1976	05 23	38°57′	70°22′	6	2	0	0	246	90	−1
12	19.IX 1976	17 51	38°57′	70°34′	10	2	166	15	346	75	0,2

Key:
1. Date
2. Time, hr min
3. Hypocenter coordinates
4. North latitude
5. East longitude
6. Magnitude M
7. Compression axis P
8. Extension axis T

medium that contains structural elements of different rigidity individual elements can slip as a single entity relative to the surrounding medium. Rupture deformations with opposite signs can occur on the opposing faces of such an element, so that some fraction of the corresponding earthquake mechanisms will be known to be inconsistent with the long-term STD. Blocks of strata of rock that stick out along a system of weakened planes may emerge as such elements. Descriptions of such systems are described extensively in the geologic literature, for example as combinations of planes of stratification, anisotropic distribution of fracturing, caused by different ranks of cleavage, of a proper network of tectonic faults.

It has been established by numerous theoretical and experimental investigations that two faults begin to exert an influence on each other at a distance apart of about two characteristic dimensions [16]. Therefore the

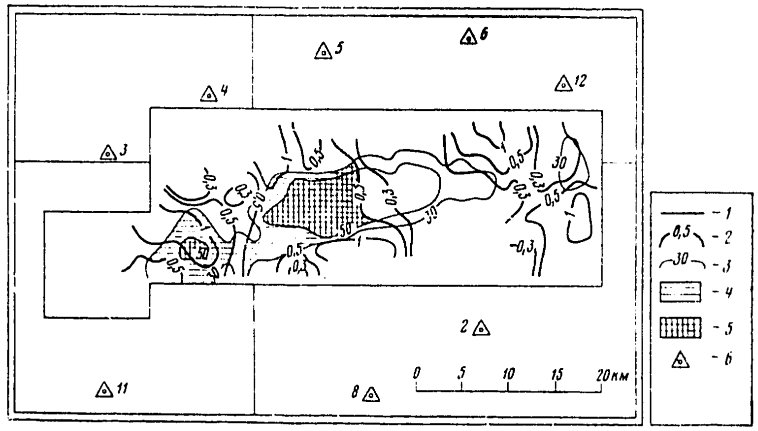

Figure 5. Intersection of mechanism determination density map and map of ratio of number of "atypical" mechanisms to number of "typical" mechanisms: 1 -- contours of investigated region; 2 -- isolines of ratio of number of "atypical" mechanisms inconsistent with long-term STD of region, to number of "typical" within 2' × 2' area; 3 -- isolines of number of epicenter mechanism determinations; 4 -- zones of intersection on density isoline level in 30 mechanisms; 5 -- likewise on level in 50 mechanisms; 6 -- stationary seismic stations.

the possibility of earthquakes, related to the simultaneous existence of two nearby faults, is not ruled out. Such a situation can arise during simultaneous displacement along a fault and fledgling system of smaller faults, as apparently occurred in the epicenter of the 6.6 magnitude Sarykamysh earthquake of 5 May 1970 [17]. In our case the hypothesis that earthquakes with complex displacement in their epicenters are confined to zones in which macrofracturing of the rocks is concentrated is indirectly confirmed by the observed confinement of such earthquakes to two parts in the center of the Peter I range with high-level seismic activity and many inconsistent mechanisms (Figures 1 and 3).

We note that the use of a theoretical source in the form of three balanced orthogonal pairs of momentless forces for the description of an earthquake mechanism enhances the capabilities of geophysical interpretation. Here, just as in the case of a source of two balanced orthogonal momentless dipoles, it is possible, as a rule, to identify two alternative surfaces of a main fault and lines of main displacements along them. At the same time an additional parameter of an epicenter mechanism -- Lode-Nadái coefficient μ_m -- provides an idea of the nature of the shear deformation process in an earthquake epicenter.

Thus, the observable features in the distribution of the signs of first movements in P- and S-waves in some earthquakes can be explained only within the framework of the theory of shear deformations in an epicenter without the involvement of fracturing and three-dimensional deformation. Nevertheless it is important to remember that such features can be interpreted formally from the point of view of a source as the superposition of a center of expansion or compression and an ordinary source of pure shear. We note that in this case the nodal surfaces with small ratios ε of three-dimensional deformation to shear deformation are close to the nodal surfaces of the triple-dipole source used by us with $\mu_m \sim \varepsilon$. If the possibility of phase transformations at relatively shallow depths in the earth's crust is left outside of the framework of the discussion, an attempt may be made to explain the addition to a source of a spherical part in the nature of an expansion center from the standpoint of dilatation during shear deformation. However, for adding a compression center, i.e., a center of consolidation of the rocks in the epicenter at the initial moment of an earthquake, it is hard to find simple physical explanations, considering the already existing great hydrostatic pressures in an earthquake epicenter. At the same time the indirect realization of complex displacement in an earthquake epicenter is associated with other features, described in this work, of the manifestation of the seismotectonic process.

7. Conclusions

Within the confines of the uniformly deformed region of the Peter I range, three explicit types of earthquakes are observed, which differ substantially from each other by the character of the fracturing deformation in their epicenters. In geological terminology upthrust (overthrust), slip and upthrust-slip earthquakes, which account for more than 70% of the total number of earthquakes, and whose epicenter mechanism is consistent with long-term seismotectonic deformation, are typical of this region. In addition, there are two classes of atypical earthquakes.

The first class of such earthquakes, which amount to about 25% of the total number of earthquakes, consists of thrusts, slips and slip strikes that do not correspond to the STD tensor of that region. This discrepancy presumably can be attributed to the displacement of more rigid elements of the medium as a single entity during the process of tectonic deformation, in which the movement of each such element on one of the boundaries must be consistent with the mechanism of overall deformation.

The second class of atypical earthquakes is represented by simultaneous movement in the epicenters along several fault surfaces, which is manifested in a nonquadratic distribution of the signs of first manifestations on the surface of the focal sphere surrounding the earthquake epicenter. It is suggested that these earthquakes are confined to zones in which macrofracturing is concentrated.

BIBLIOGRAPHY

1. Gotsadze, O. D., et al, "Analysis of Mechanism of Earthquakes," TR. GEOFIAN SSSR [Proceedings of Geophysical Institute of the USSR Academy of Sciences], No 40 (166), 1957.

2. Krestnikov, V. N. and I. G. Simbireva, "Relationship Between Tectonic Structure and Features of Distribution of Dynamic Parameters of Earthquake Epicenters," Sb. "Zemnaya kora seysmoopasnykh zon." Verkhnaya mantiya [The Collection "The Earth's Crust in Seismically Dangerous Zones." The Upper Mantle], No 11, Moscow, Nauka, 1973.

3. Nersesov, I. L., et al, "Feasibility of Forecasting Earthquakes by Example of Garmskiy Rayon of Tadzhik SSR," Sb. "Predvestniki zemletryaseniy" [The Collection "Precursors of Earthquakes"], Moscow, VINITI, dep. No. 5498-73, 1973.

4. Vesson, R. L., V. G. Leonova, A. B. Maksimov, I. L. Nersesov and F. G. Fisher, "Results of Joint Field Seismologic Investigations of 1975 in Peter I Range," "Sb. sovetsko-amerikanskikh rabot po prognozu zemletryaseniy" [Symposium of Soviet-American Studies on Earthquake Prediction], Vol 1, Book 1, Dushanbe-Moscow, Donish, 1976.

5. Lukk, A. A. and S. L. Yunga, "Seismotectonic Deformation of Garmskiy Rayon," IZV. AN SSSR. FIZIKA ZEMLI [News of the USSR Academy of Sciences. Geophysics], No 10, 1979.

6. Simbireva, I. G., A. A. Lukk and I. L. Nersesov, "Changes of Dynamic Parameters of Weak Earthquake Epicenters in Connection with Occurrence of Strong Earthquakes," Sb. "Regional'nyye issledovaniya seysmicheskogo rezhima" [The Collection "Regional Studies of Seismic Conditions"], Kishinev, Shtiintsa, 1974.

7. Mikumo, T., M. Otsuka and K. Oike, "Focal Mechanism of Microearthquakes in Wakayama Region," ZISIN. J. SEISMOL. SOC. JAPAN, Vol 23, No 3, 1970.

8. Shiono, K., "Focal Mechanism of Microearthquakes in Wakayama Region (Part 1)," ZISIN. J. SEISMOL. SOC. JAPAN, Vol 23, No 3, 1970.

9. Takagi, S., "Do Earthquakes Occur Due to Stress?" PAPER METEOROL. GEOPHYS., Tokyo, Vol 23, pp 1-21, 1972.

10. Legros, H. and P. H. Trong, "Repartition non ortogonale des sens du premier mouvements des ondes P," TECTONOPHYSICS, Vol 27, No 3, 1975.

11. Balakina, L. M. and V. V. Kislovskaya, "Features of Epicenter Mechanisms of Certain Deep Earthquakes in Sea of Okhotsk," IZV. AN SSSR. FIZIKA ZEMLI, No 8, 1975.

12. Lukk, A. A., S. L. Yunga and V. G. Leonova, "General View of Nodal Surface in Crustal Earthquakes," "Sb. sovetsko-amerikanskikh rabot po prognozu zemletryaseniy," Vol 1, Book 2, Dushanbe-Moscow, Donish, 1976.

13. Yunga, S. L. and R. L. Vesson, "Features of Earthquake Mechanism in Garm Region," "Sb. sovetsko-amerikanskikh rabot po prognozu zemletryaseniy," Vol 2, Book 1, Dushanbe-Moscow, Donish, 1979.

14. Kostrov, B. V., "Mekhanika ochaga tektonicheskogo zemletryaseniya" [Mechanics of Tectonic Earthquake Epicenter], Moscow, Nauka, 1975.

15. Yunga, S. L., "Determination of Earthquake Mechanism Based on Arrivals of Longitudinal Transverse Seismic Waves," DOKL. AN SSSR [Reports of USSR Academy of Sciences], Vol 233, No 6, 1977.

16. Cherepanov, G. P., "Mekhanika khrupkogo razrusheniya" [Mechanics of Brittle Fracturing], Moscow, Nauka, 1974.

17. Aptekman, Zh. Ya., T. S. Zhelankina and N. V. Shebalin, "Position of Fracture Plane in Epicenters of Certain Strong Earthquakes," Sb. "Vychislitel'naya seysmologiya" [The Collection "Computer Seismology"], No 11, Moscow, Nauka, 1978.

[8144/1599-7872]

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